Dr Ichiro Shibasaki is Chief Research Fellow at Asahi Kasei Corporation's central R&D division and is responsible for overseeing annual production of 1,400 million InSb/InAs thin film Hall sensors (~70% of total world production) manufactured by Asahi Kasei Electronics, a wholly owned subsidiary of Asahi Kasei Corp. The Hall sensors are used in modern electronic equipment for controlling DC motors in VCRs, CD-ROM drives and most recently for reducing the power consumed by electric motors in household washing machines. Dr Shibasaki has played a pivotal role in establishing Asahi Kasei Electronics as the world leader in InSb/InAs thin film Hall sensors. In this interview he gives us a behind the scenes glimpse of the events and turning points leading to the formation of a multimillion dollar industry based on Edwin Herbet Hall's observation in 1880, that a magnetic field distorts the equipotential lines in a current-carrying conductor: the Hall effect.

by Gen Kida

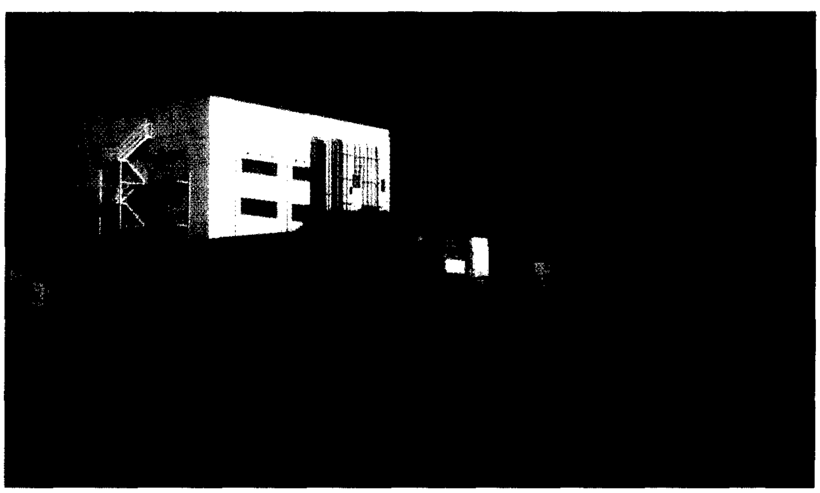
木田源

Development and future prospects of high sensitivity InSb/InAs Thin Film Hall sensors

The Early Days

Dr Shibasaki recalls the events of 1973, when Asahi Kasei Corp decided that InSb was the material of choice for fabricating high sensitivity Hall devices. "I joined Asahi Kasei in 1974, when the Company was actively involved in developing a wide range of sensors for triggering automobile air bags. I was asked to investigate the possibility of using magnetic sensors for such applications. In those days high performance Hall devices were made by slicing and polishing single crystal InSb blocks to thickness of about 10 micrometers and evaporating metals for forming Ohmic contacts. Such devices were very expensive, costing several thousand Yen and what's more, they were in short supply. I had read some Japanese research papers published between 1960 and 1970 about the magnetic properties of polycrystalline InSb thin films and we decided to investigate the possibility of producing low priced, high sensitivity InSb thin film Hall sensors by vacuum evaporation using mica substrates. In the early 1970s, there was tremendous industrial activity related to the development of audio players and in particular 'direct drive' motors for low noise amplifiers. This was a new and potentially even larger market for high performance Hall sensors. So we were confident that there would be a market for Hall sensors, but we had to overcome some very difficult problems before the first batch of commercial InSb thin films Hall sensors were marketed by AKE in 1980."

Asahi Kasei Electronics with a view of Mt Fuji in the background.



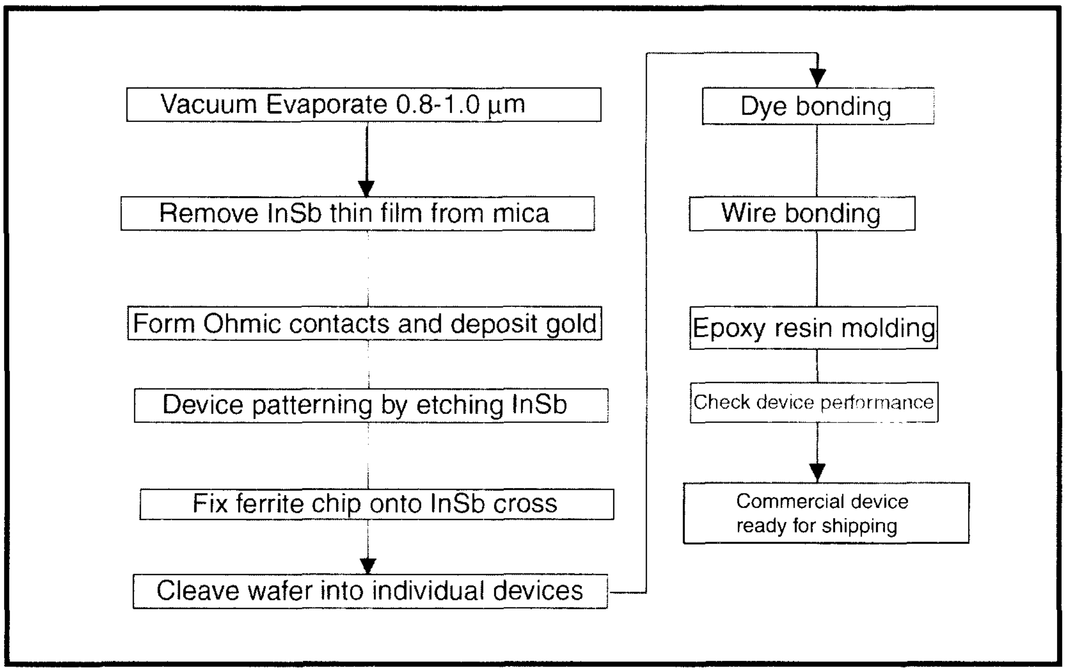


Fig. 1: Process developed for fabricating polycrystalline InSb thin film Hall Devices

Breakthroughs and Landmarks

The initial goals were to improve the stoichiometry and uniformity of the InSb films. Dr Shibasaki's group achieved this by devising a multi-source evaporation system with time dependent substrate heating, where InSb was sequentially evaporated from several sources, enabling the deposition of highly stoichiometric, 1mm thick InSb films onto mica substrates. This method overcame the problems associated with the large differences between the vapour pressures of indium and antimony during evaporation. The resulting films showed electron mobilities as high as 20,000 cm^2/Vs at room temperature.

Another problem to resolve was related to the actual device fabrication process. Dr Shibasaki explains that, "in the very early days, we defined the Hall device structures by evaporating InSb through metal masks. It was a simple and inexpensive method for fabricating the devices. But we had problems with device performance and reliability. So we decided to use photolithography for processing InSb Hall devices. I think this was probably the first time ever that photolithography had been used for fabricating Hall devices."

But in-spite of improvements in device reproducibility, the group found that the sensitivity of the Hall sensors was still not sufficient for the

Table 1

Year	Event
1973	Feasibility study for development of InSb thin films Hall sensors
1974	Establish basic structure and evaporation method of InSb thin film Hall sensors
1975-76	Assess potential for audio player market
1977-78	Planning and development of manufacturing facilities
1980 August	Start mass production of high sensitivity InSb thin film Hall sensors
1981 April	Achieved target of 1m units per month; start mass production for video applications
1982	Reduction in the number of Hall sensors manufactured due to decline in demand for video tape recorders
1983	Increase production to 5m per month due to tremendous increase in demand for video tape recorders
1985	Manufactured 100m Hall sensors per month
1986	Increased production to 170m per month; increased demand for floppy disk drive applications
1997-1999	Report on electrical properties of InSb magnetoresistance elements
1999-2001	Hybrid Thin Film Hall effect ICs

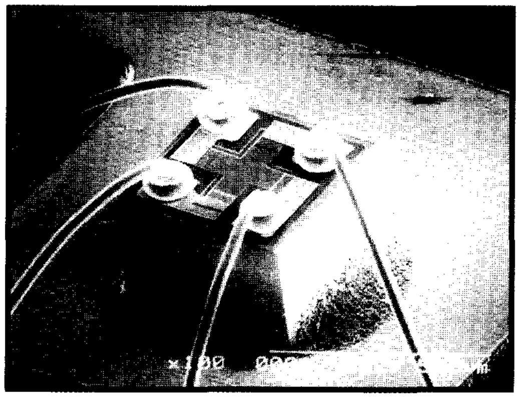


Fig.2: Bonded InAs thin film Hall element chip prior to epoxy encapsulation.

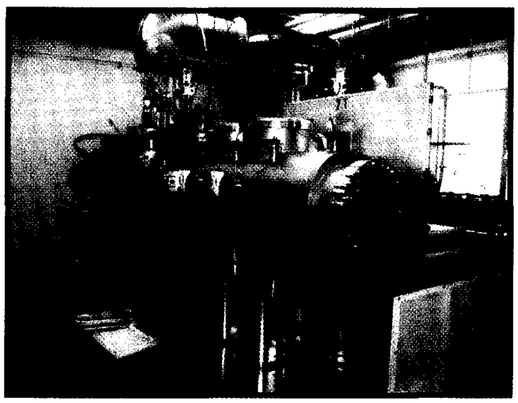


Fig3 : The current multi-wafer MBE system used for growing InSb/InAs Hall device structures.

type of commercial applications that were being planned. So a novel solution, based a theoretical study by Dr Shibasaki, was proposed. "My calculations showed that the sensitivity of the devices could be improved by sandwiching the InSb thin films between two layers of a ferrite material. So we had to develop a reproducible way of removing the 1mm polycrystalline layer of InSb from the mica substrate and transfer it onto a ferrite one. We were successful in achieving these aims and reported the results to the scientific community in 1978. The sensitivity of the InSb Hall devices was improved by a factor of five," he says.

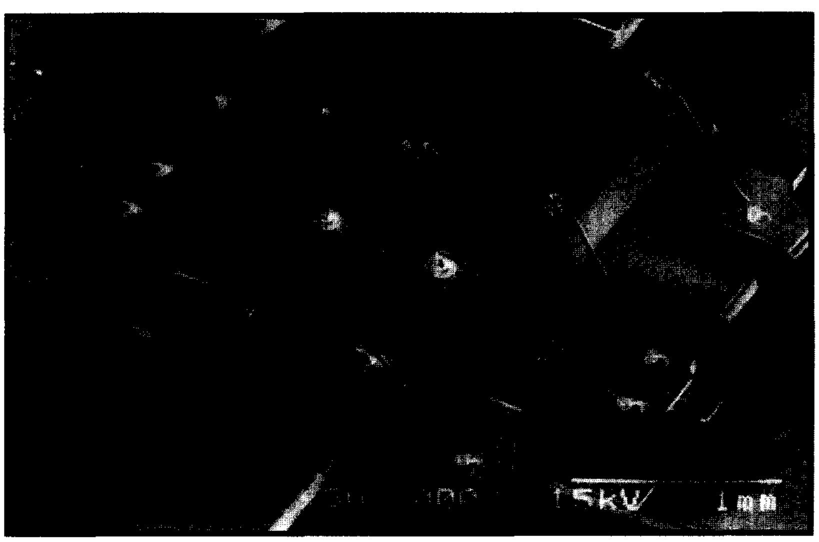


Fig. 5: InSb thin film hybrid Hall IC consisting of a silicon IC amplifier fabricated by conventional bipolar processing.

But there were still two other processing steps to optimise before a commercial Hall sensor was realised. Dr Shibasaki describes the situation in 1979. "We still had to sort out some basic problems before manufacturing on a large scale could be contemplated. The first problem was associated with electrical wiring of the devices. We were soldering wires to the devices, a method that was not compatible with mass production. So we developed a new electrode structure that allowed gold wire bonding to form electrical connections between the Hall chip and dye. The bonding had to be done at low temperature so as not to damage the one micron thick InSb layer fixed to the ferrite substrate. We managed to achieve wire bonding at 100°C. The final problem was packaging the final device structure. For this we used a standard epoxy resin process used in the semiconductor industry, but it was probably the first time that epoxy molding had been used for encapsulating high sensitivity sensors. At last we had achieved our goal of fabricating a high performance InSb thin film Hall sensor."

Table 1 is a list of the major events and achievements during the development of polycrystalline InSb thin films and Fig.1 shows the final process used to fabricate the InSb Hall devices.

Multi-wafer MBE for mass production of InAs/AlGaAsSb Hall sensors

The performance of the polycrystalline InSb thin film Hall sensors was sufficient for use in VCR, FDD and CD-ROM drives, but these devices could not be used in high temperature environments such as engine compartments of cars where stable operation was required up to 1500°C. The input resistance temperature coefficient was found to be too large at -2.0%/ °C between 10°C and 100°C.

A conventional solution would have been to use GaAs, which has a larger band gap than InSb, for fabricating Hall sensors for such applications. But according to Dr Shibasaki, "the magnetic sensitivity of GaAs was too low for applications such as current sensors. So we decided to try InAs which has a larger bandgap than InSb and a much higher electron mobility than GaAs. Our goals were very clear. We wanted to grow large quantities of single crystal InAs thin films on GaAs substrates and decided to invest in a multi-wafer molecular beam epitaxy system capable of producing twelve, two inch wafers at a time; a unique approach in this industry at the time."

Dr Shibasaki's group used a three chamber MBE system to directly grow 0.5mm thick, silicon doped InAs films on GaAs(100) substrates and in-spite of the 7% mismatch, the resulting InAs thin films exhibited remarkable electrical properties: an electron mobility of 11,000 cm^2/Vs; sensitivity of 100mV/6V at 0.05T; Hall voltage temperature dependence of -0.18%/°C. The multi-wafer MBE system enabled the manufacture of 100m Hall elements per year. A typical 360mm x 360 mm, Si-doped InAs thin film Hall element is shown in Fig.2.

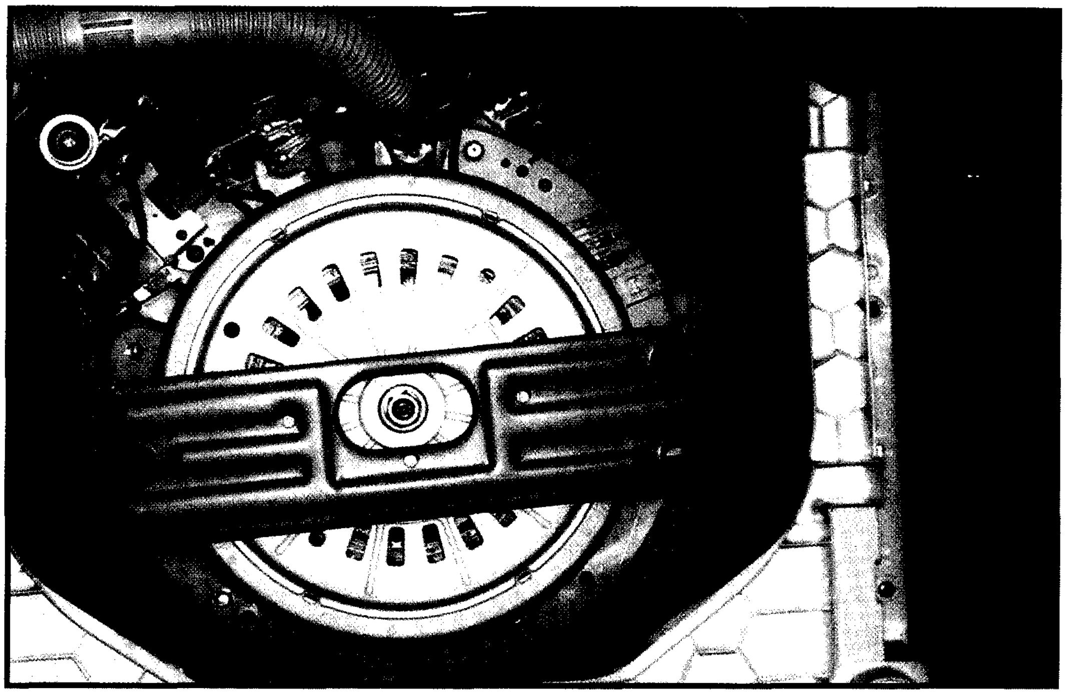
But there were still demands for InAs thin film Hall sensors with a low temperature dependence as well as a magnetic sensitivity compatible with InSb thin films. Dr Shibasaki's group met these demands by growing an InAs quantum well between AlSb barrier layers. The resulting structures yielded electron mobilities of 20,000 cm^2/Vs with a typical Hall voltage output of 600mV/6V at 0.1T. The sensitivity of these devices was about 2 times better than the simpler silicon doped InAs structures and 5 times better than GaAs Hall devices.

The future: digital magnetic sensors and energy conservation

Dr Shibasaki is very clear about the role of Hall devices in the future."I think that our Hall devices can contribute to electrical energy saving and the efficient use of electronic materials. For example, the availability of our small Hall sensors has led to a reduction in the size of brushless DC motors and peripheral electronic components. This miniaturisation has not only enabled the production of compact electronic equipment but it has also resulted in a reduction of the quantity of materials used for manufacturing such equipment. Statistics show that approximately 180m VCRs and PCs are manufactured annually and by simply reducing the amount of material used for electrical power systems by 1gram per system, then it would be possible to reduce the total amount of material used by 180 tonnes. As a result less energy would be required to manufacture the components which would in turn contribute to a reduction in the amount of carbon dioxide released into the atmosphere.

"Also according to the Japan Noryoku Society, electrical motors consume approximately 50% of the total electricity generated in this country and that a 1% reduction of the electricity consumed by electric motors would result in power stations having to produce 500MW less electricity.This is a definite possibility because power brushless motors with a permanent magnet rotor and Hall effect magnetic sensors require less electrical energy than conventional motors.The Hall motor can change rotational speed by sensing the position of magnetic rotors. Conventional AC induction

Fig.6: InSb thin film hybrid Hall IC in a commercial washing machine.



motors cannot change their speed of rotation in response to changes in load conditions. So I think magnetic sensors will be a key component for future motors and actuators."

Asahi Kasei has already taken the first step towards such applications and developed digital hybrid Hall ICs, comprising an InSb Hall element and a silicon integrated circuit amplifier and signal processor as shown in Fig. 5. The hybrid Hall IC incorporates a special direct-coupled amplifier that directly converts the Hall output voltage of the InSb Hall sensor to the required digital signal. Fig. 6 shows an application of these hybrid Hall ICs in a household washing machine to detect the rotation of a permanent magnet rotor on the rotating drum containing the laundry.

Asahi Kasei has also recently developed current sensing elements using Hall devices and 1mm thick single crystal InSb thin film magnetoresistance (MR) elements for the detection of rotating gears. The output signal of the MR elements is independent of the angular velocity of the gears, thus making

Dr Shibasaki holding a current sensor and Hall motor

it an extremely useful for applications such as automobile engines, where safety is very important.

Dr Shibasaki sums up his vision of the future for InSb/InAs Hall and MR elements as devices that will enable the production of 'high quality power'. In Dr Shibasaki's words, "We can use Hall and MR devices for precisely controlling the rotation of brushless motors, thereby reducing acoustic and electrical noise. These devices can also be used for precisely controlling the angular velocity of rotors, thus contributing to savings in electrical and mechanical energy.

In other words, the Hall devices will be used for fabricating intelligent motors. The keywords for the future are non-contact magnetic Hall and MR sensors."

Further information:

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Asahi Kasei Electronics:shttp://www.asahi-kasei.co.jp/ake/en/index.htm